Arctic Climate Observations Using Underwater Sound (ACOUS)

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LONG TERM GOALS

The Arctic Climate Observations using Underwater Sound (ACOUS) Project is a joint US/Russian global climate change research program. The goal of the ACOUS Project is to monitor changes in water temperature in the Arctic Ocean through the use of underwater acoustic remote sensing technology, exploiting the fact that the speed of sound propagation in water is a function of the water temperature.

OBJECTIVES

The objective of the ACOUS Project is to advance the understanding of short and long-term variability in the Arctic Ocean and its relation to global climate trends. Acoustic measurements made in 1994 and again in 1999 have shown significant warming of the Arctic Ocean with average maximum temperature increases of 1°C since the early 1990's. These results are consistent with direct temperature measurements made by the SCICEX Arctic submarine cruises that have validated the acoustic method.

APPROACH

ACOUS ocean temperature data will augment and complement data acquired from other programs using satellite temperature, altimeter and synthetic aperture radar as well as direct ocean measurements planned using moorings, drifting buoys and AUV's. Methods will then be developed to incorporate measurements supplied by the ACOUS Project into databases supporting models for Arctic Ocean-ice-atmosphere interactions, Arctic Ocean circulation, and climate prediction. By improving supporting databases, the predictive capabilities of these models will be enhanced, thus enabling more accurate forecasts of Arctic environmental changes, which are important indicators of environmental changes occurring on as global scale.

WORK COMPLETED

A field effort was conducted in September-October 2000 to recover an autonomous vertical acoustic receive array and recording package that was deployed in the Lincoln Sea on October 1, 1998, about 100 miles north of Ellesmere Island, Canada, at 84-03.4 N / 066-24.9W. The array recorded a signal transmitted by a Russian acoustic source located near Franz Josef Land (over 1250 km away), which transmitted an M-sequence acoustic signal at 20.5 Hertz for 20 minutes every 4 days. The vertical bottom moored acoustic receive array was 518 meters in length and was deployed through the sea ice

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14. ABSTRACT
The Arctic Climate Observations using Underwater Sound (ACOUS) Project is a joint US/Russian global climate change research program. The goal of the ACOUS Project is to monitor changes in water temperature in the Arctic Ocean through the use of underwater acoustic remote sensing technology, exploiting the fact that the speed of sound propagation in water is a function of the water temperature.

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in water 545 meters deep. The field effort in September-October 2000 was not successful due to adverse weather conditions and support aircraft malfunctions.

Additional funding was provided by ONR to conduct another field effort in March 2001 to attempt the recovery of the autonomous vertical acoustic receive array and recording package. The field effort was staged out of Canadian Forces Station (CFS) Alert, Canada, on the north coast of Ellesmere Island. On 20/21 March 2001 a SAIC team successful recovered the ACOUS Lincoln Sea Receive Array. The acoustic data from the array data package was downloaded at SAIC, Gulfport, MS, where the acoustic array and recording package were designed and assembled.

RESULTS

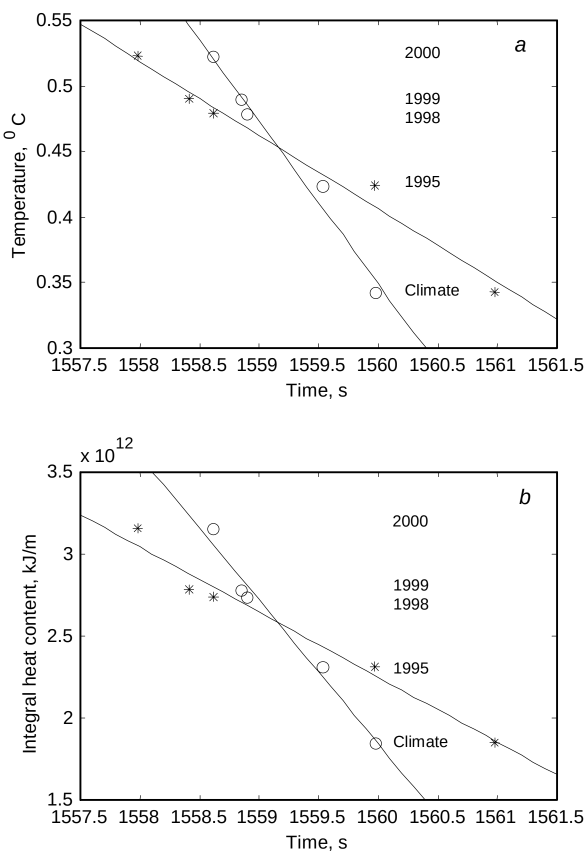

Fig.1. a – the section-average temperature of the AIW layer derived from the SCICEX transect of different years and the climatology data versus the travel time of modes 2 (stars) and 3 (circles) of an acoustic signal at 20.5 Hz propagated over the SCICEX section, and the best linear fit for the relationship between these characteristics;
b – same as a, but for the integral heat content of the AIW layer.

In the Arctic underwater channel, the acoustic energy of low-frequency signals propagates in well-defined waveguide modes. It has been shown previously that the section-averaged *maximum* of the AIW is strongly correlated with the mode 2 and 3 travel times [1]. Fig. 1 from this year's work [2] shows the relationship between the travel times of modes 2 and 3 on the path along the SCICEX

section and the *total* section-average temperature (averaged over range and depth) (upper panel) from which the heat content can be computed (lower panel) of the AIW layer. The relationship of modal travel times and the section-average AIW parameters is well approximated by linear regressions, a very important result, that shows the value of monitoring acoustic travel times for making measurements of these important AIW properties. The standard deviation from the best linear fit for the AIW temperature as a function of the travel times of modes 2 and 3 is equal to approximately 9 m^0C. The standard deviation of the best fit for the AIW heat content is approximately 7×10^{10} kJ/m (slightly greater for mode 2 and slightly less for mode 3). The increase in section average heat content of ~ 10^{12} kJ/m of the AIW over the last 5 years shown in Fig. 1(b) represents an average heat flux of ~ 2.8 W/m^2 along the 2269 km transect. We can make the same calculation as a function of range along the section using the SCICEX data and we find that in the regions of the cores of the AIW circulation near the Lomonosov Ridge, Mendeleyev Ridge, and the Chukchi Rise the heat flux is ~ 6 W/m^2. Presumably some large fraction of this heat is circulating out of the Arctic Ocean, but the rest is warming the Arctic waters adjacent to these warm cores that has been noted in the SCICEX data [2], and also penetrating the pycnocline where it can melt the sea ice. Rothrock et al. [3] calculate that a 4 W/m^2 increase in heat flux from the ocean to the ice could explain the observed 1.4 m thinning of sea ice over the last 20 years. Clearly the numbers above show that the AIW warming is, not surprisingly, a likely contributor to the observed sea ice thinning.

The ACOUS Lincoln Sea Receive Array recorded data until June 1, 2000, when the batteries were depleted. The signal recordings on the array showed that the acoustic source operated successfully for 14 months from October 10, 1998 until December 8, 1999. Initial processing of the time series of acoustic thermometry data collected on the array has been completed. The absolute travel times of the acoustic modes filtered from the ACOUS signals on the array still need to be determined with the maximum precision, which requires additional, conclusive verification of the absolute timing of signal transmissions and receptions.

The relative modal travel times, i.e., the difference between the arrival times of different modes on the array also depend upon the vertical temperature profile. Since the relative modal travel times are independent of absolute times, we investigated these pending final analysis of the absolute timing. Mode 1 of the acoustic signal at 20.5 Hz, propagating under the ice in the Arctic Ocean, is trapped by the upper acoustic channel that is formed by the sea surface and the thermocline between the upper mixed layer of cold and less saline Arctic waters and the Arctic Intermediate Water (AIW) layer. Under such environmental conditions, the typical group velocity of mode 1 is considerably slower than the group velocity of the higher modes, particularly modes 2 and 3, that propagate in the entire waveguide localized mainly in the AIW layer. On a transarctic path this leads to considerable delay in the arrival time of Mode 1 relative to the arrivals of the higher modes. The difference between the travel times of mode 1 and modes 2 and 3 on the ACOUS path was expected to be about 8.0 – 8.5 sec, predicted from the results of the Transarctic Acoustic Propagation (TAP) experiment [1] and the results of numerical modeling of the acoustic propagation for the typical conditions along the path. The travel time difference of mode 1 and modes 2 and 3 measured in the ACOUS signal recordings was close to the expected value for the first eight months of observations, but then it was steadily decreasing and had fallen to 6.5 – 6.8 sec by the end of observations.

This interesting decrease in the relative travel time was the focus of a particular study that was carried out using numerical modeling of the acoustic propagation and the most recent oceanographic data collected in the regions along the acoustic path. The modeling results show that under certain

environmental conditions, when the maximum temperature of the AIW layer reaches approximately 2.7°C, and the upper boundary of this layer expands above 100-m depth, the group velocity of mode 1 at 20.5 Hz becomes considerably higher than the group velocity of mode 2. These conditions have only been observed to date in the Eastern Arctic where warm Atlantic water enters via the Fram Strait. Thus a shortening of the relative travel time between mode 1 and mode 2 becomes an indication of an increase in the maximum AIW temperature and a shoaling of the thermocline which can signify a thinning of the cold halocline layer that separates the AIW from the sea ice. Since this effect is frequency dependent, particular frequencies and waveforms can be transmitted in future systems that would be designed to be most sensitive to changes in the depth of the thermocline.

IMPACT

The acoustic observations taken by the ACOUS Lincoln Sea Array during the period October 1998 to December 1999 indicate a strong and extended warming of Atlantic waters that occurred in the Nansen Basin by the end of 1999. This acoustic measurement is consistent with the continued warming of the AIW in the Arctic Ocean observed during the SCICEX-2000 cross-basin transect. These measurements and the modeling show that acoustic thermometry can also be used to monitor average thermocline depth along the propagation path.

The warming of the AIW in the Arctic Ocean that started in the early 1990's has continued through the fall of 2000. With the end of the dedicated SCICEX cruises one of the most fruitful eras of data collection that has driven much of our newly formed understanding of the Arctic Ocean is at a close. New technologies are needed. Acoustic thermometry can provide long-term high-resolution time series of changes in the Arctic Ocean temperature, heat content, and thermocline depth. It is remarkable that the linear relationship between the section-average AIW temperature and heat content, and the mode 2 and 3 travel times is not only consistent with the recent SCICEX measurements but the 40 year average climatology as well. An acoustic thermometry network of sources and receivers collocated on bottom mounted Arctic Ocean moorings as proposed in several new initiatives could provide spatially synoptic time series measurements in the post SCICEX era.

TRANSITIONS

None

RELATED PROJECTS

Submarine Science Expeditions (SCICEX) starting in 1993 and extending through 2000.

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PATENTS

None